

## Fish distribution and zonation along a tropical African river, the Rokel/Seli River, Sierra Leone, West Africa

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Received 17 December 2009; accepted 22 February 2010

**ABSTRACT.** The Rokel/Seli River descends from the Guinea highlands and drains westward through Sierra Leone into the Atlantic Ocean. It lies within the Upper Guinean faunal region. The river has low mineralisation and buffering with conductivity varying from 14–55  $\mu\text{S}$  and pH from 6.8–7.8 whilst temperature ranges from 21–32°C. Sampling along its length over a 12 month period showed that the number of species diminishes significantly upstream from 50 at the richest downstream point to 6 in the highest streams sampled. The major change occurs at the Bumbuna Falls which, at 136 m above mean sea level, also lies at the point of maximum change in gradient between the upland rhithron zone and the lowland potamon zone. The region above the Falls has 29 species, while 62 were recorded from the lowland reaches of the river. The Falls appear to be a barrier to fish movement as well as a barrier to the distribution of some species such as *Lates niloticus*. Yields from fishing also increase downstream from 0.87 t.km<sup>-1</sup> in the upper area to 2.58 t.km<sup>-1</sup> in the lowland reaches. Three fish freshwater zones were identified: an uppermost ‘small cyprinid zone’, typified here by *Barbus liberiensis*, starting around 290 m.a.msl; a ‘large cyprinid zone’ characterised by *Barbus sacratus*, and *Labeo parous* from above the Falls at 165–290 m.a.msl, and a lowland zone, below 136 m.a.msl, dominated by cichlids and catfishes. The large cyprinids move into the upper small cyprinid zone during the spawning migrations of the early rains. A total of 68 freshwater species was found throughout the system, rather higher than would be predicted from other African rivers. The fish assemblage is also very characteristic, having more than 35% of the species as regional endemics confined to the Upper Guinean region with the small cichlids and tilapias showing particularly high levels of endemism.

**RÉSUMÉ.** Le fleuve Rokel / Seli descend des montagnes de Guinée et coule vers l’ouest, passe à travers Le

Sierra Leone et se jette dans l’Océan Atlantique. Elle s’étend dans la région de la Haute Guinée. Le fleuve contient un faible degré de substances minérales avec une charge de conductivité électrique variant de 14 à 55  $\mu\text{S}$  et de 6.8 à 7.8 pendant que les écarts de température sont entre 21 à 32 degrés. La technique d’échantillonnage appliquée tout au long du fleuve pendant plus de 12 mois a démontré que le nombre d’espèces va diminuant sensiblement en amont du fleuve : de 50 en amont, cela atteint le point 6 en aval. Le grand changement se produit aux chutes Bumbuna, à 136 m au-dessus du niveau de la mer, dont le point culminant d’inclinaison est entre la haute-zone rhithron et la basse-zone potamon. La région au-delà des chutes contient 29 espèces pendant que 62 ont été enregistrées en amont du fleuve. Les chutes forment un obstacle tant au mouvement poissonnier qu’à la répartition de quelques espèces comme le *Lates niloticus*. Aussi le rendement de la pêche augmente-t-il de l’aval de 0.87 t.km en amont à 2.58 tkm dans les régions inférieures. Trois couches de poissons ont été identifiées : en grand nombre la zone de petit Cyprinidae classifié comme *Barbus liberiensis* variant autour de 290 metre au dessus du niveau de la mer ; une zone de grande Cyprinidae caractérisée par *Barbus sacratus* et *Labeo parous* d’au-delà des chutes de 1665-290 metre au dessus du niveau de la mer et une zone inférieure, en dessous de 136 metre au dessus du niveau de la mer, est dominée par les Cichlidae et les poissons chats. Les plus grands Cypirinidae se déplacent dans la partie supérieure, en amont du fleuve, pendant la période de reproduction et pendant la période des pluies. Un total de 68 espèces d’eau douce étaient trouvées dans le « système » en nombre plus élevé que les prédictions faites au sujet d’autres fleuves africains. Le ban de poisson est aussi très caractéristique ayant plus de 35 % d’espèces comme la région endémique confinée dans la région de la Haute Guinée avec de petits Cichlidae et des espèces de *Tilapia*.

**KEY WORDS:** fish distribution, zonation, African rivers, freshwater ecoregions, Sierra Leone

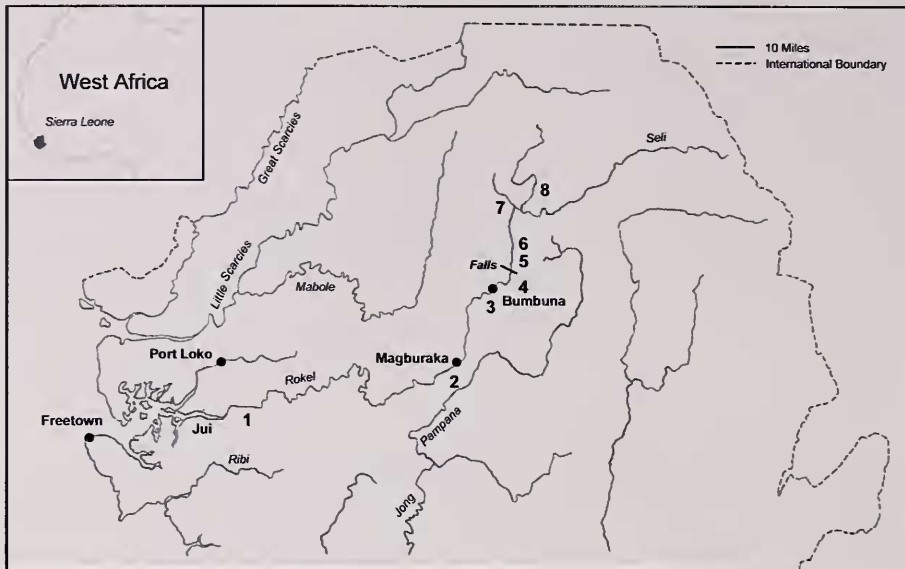


Fig. 1. The Rokel/Seli River in northern Sierra Leone showing sampling sites.

## INTRODUCTION

The Rokel/Seli River, called the Rokel in its lower and the Seli in its upper reaches, is one of a series of narrow, more or less parallel river basins draining the Guinea highlands into the Atlantic, none of which are particularly long in African terms.

The region has been termed the Guinean (Lowe McConnell 1987), or the Upper Guinean (Leveque & Paugy 1999, Abell *et al.* 2008), while Daget (1962; Daget & Iltis 1965) termed it, perhaps climatically more correctly, the 'Atlantico-Guinean'. The region is more or less co-incident with the island of equatorial forest extending largely throughout South West Guinea, Sierra Leone, Liberia and southern Ivory Coast. It is surrounded by the savannah of upper Guinea and the 'Dahomey-gap'. This surrounding savannah region has been termed the Sudanien, based on the clear similarities of the fish assemblages occurring in river basins from the Niger to the Nile (Daget & Durant 1981; Lowe-McConnell 1987; Roberts 1975; Greenwood 1983).

Surveys of Sierra Leone rivers have been very patchy. Daget (1950) made a small collection, and sundry collections have been taken by a variety of collectors over the years, most notably Thys van den Audenaerde (1967). Essentially, most of the work up to this point has been taxonomic, the culmination of which is an overall guide to the taxonomy and identification of West Africa fresh water fishes (Leveque & Paugy 1984; Paugy *et al.* 2004), and a checklist for Sierra Leone (Paugy *et al.* 1990).

On the broader ecological front there has been one three-year study on the seasonal changes in the fish assemblage in the lower portion of another Sierra Leone river, the neighbouring River Taia (Payne *et al.* 1989). This notwithstanding, there has

been no overall appraisal of the fish assemblages within Sierra Leone rivers and their distinctiveness as part of the Guinean region.

A pre-impoundment study of the Seli River for the Bumbuna Hydroelectric Project resulted in sampling the river from its upland headwater streams to the estuary (Fig. 1) thereby allowing both the river assemblage and changes in species composition down the length of the river to be categorised. Huet (1949) showed how fish species and communities change with altitude along temperate European rivers. Similar changes occur in tropical rivers including those of Africa (Payne 1986; Leveque & Paugy 1999) although they have not been systematically assessed, particularly within a single river basin. The relatively compact nature of the Rokel/Seli basin allowed this to be done over this year long survey.

## METHODS AND SITE LOCATIONS

### Site Locations

The Rokel/Seli River drains the uplands of northern Sierra Leone at altitudes of 300–400 m.amsl, where the coastal plain abuts the Guinea Plateau, and flows for some 300 km into the Atlantic through the estuarine Sierra Leone River. One particular feature of the river is the Bumbuna Falls, a cascade of around 30 m height, just above which is the site for the Bumbuna Hydroelectric Project. A significant question therefore was, to what extent do the falls influence the distribution of fishes?

Eight sites were selected in three regions, the upper, middle and lower reaches of the river, including above and below the falls (Table 1).

**Table 1.** Summary of study locations positioned on Rokel/Seli River (see Fig. 1 for locations).

Description	Region	Latitude	Longitude	Altitude (m)	No. sites
1. Rokel Bridge	Lower	8°35'05"N	12°43'16"W	11	1
2. Magburaka	Lower	8°44'12"N	11°56'21"W	86	2
3. Bumbuna Bridge	Middle	9°03'12"N	11°45'12"W	115	1
4. Below Bumbuna Falls	Middle	9°03'08"N	11°45'14"W	138	2
5. Below Bumbuna Dam	Middle	9°03'59"N	11°43'03"W	162	2
6. Above Bumbuna Dam	Middle	9°04'32"N	11°43'18"W	170	3
7. Kafogo	Upper	9°23'54"N	11°43'47"W	256	3
8. Fadugu - Bridge One	Upper	9°23'32"N	11°45'34"W	299	1

Sampling was also conducted above and below the Bumbuna Hydroelectric Dam which has been constructed above the falls, but has yet to be closed. A preliminary survey had been conducted at the site during an earlier phase (Payne & McCarton 1983). Further sites were sampled opportunistically on the estuary at Jui, and at two inflowing streams on the upper region at Kasasi and Kayakala. All sites were positioned with GPS and distances were calculated from the estuarine site at Jui.

#### Physico-Chemical Measurements

Water parameters measured at each site included pH, temperature (°C), conductivity ( $\mu\text{S.K}25$ ) and dissolved oxygen ( $\text{mg.ltr}^{-1}$  and % saturation), with instruments being recalibrated between sampling sessions. These measurements accompanied each fish sampling occasion. The altitude of the sites was measured by GPS in meters above mean sea level (m.amsl).

#### Fish Sampling

Monofilament gill nets with mesh sizes of 10, 25 and 35 mm were usually set at two or three locations at each site and checked morning and evening over 14 days for each sampling period. Where possible the nets were also used as seine nets during the day.

Traps and dip nets were also used and, where fishing communities existed, particularly at Bumbuna Town, below the Falls, and at Magburaka and the Rokel Bridge, fishers were employed to collect fishes. The catches of men (main river) and women (small streams) were checked regularly and specimens purchased opportunistically.

Each of the eight locations was sampled in January, April, July and September 2006 to coincide with early and mid-dry season, and the beginning and end of the rains. The river shows considerable rise and fall with the rains and dry season but the flow is always significant. The Rokel/Seli has a limited floodplain.

#### Potential Yield

Semi-structured informal interviews were conducted with local fishers during the 2006 baseline fish survey in an attempt to estimate the potential annual yield available from the river. The interviews were held

at Magburaka, Bumbuna and Kafogo. The potential yield was calculated for both the rainy season (May–October) and dry season (November–April) to account for seasonal variations in total catch.

Interviews were also used to calculate the average number of full-time equivalent fishers operating at the three locations each season. Total fishing effort (number of days fished per season) at each site was calculated from the average number of days per week and number of months fished by a typical fisher.

Total catch weight at each site and season was calculated for all species using their catch length (cm TL) converted into weight (g) using an appropriate length-weight relationship obtained from Fishbase (Froese & Pauly 2009). Finally, distance from the river source (km) was estimated for each location. This enabled a relationship between the potential annual yield and distance from the source of the river to be calculated for each season.

## RESULTS AND OBSERVATIONS

### PHYSICO-CHEMICAL ENVIRONMENT

#### Acidity

Water pH shows no clear trends with altitude, although it was notably higher during the lowest water levels in April. In January, pH values ranged between 6.8 at the Rokel Bridge and 7.4 at Bumbuna Bridge, whereas these increased in April to pH 7.5 and 7.8 respectively. In July, pH levels had started to fall at all sites from the high levels recorded in April, but remained above those recorded in January. In September, pH levels had returned to similar values reported during January.

The lower pH values in January, after the rains, were a result of low ionic concentrations and consequently poor buffering, together with humic compounds washed from the surrounding catchment area during the rains, which give the water a slightly acidic reaction and translucent brown colour.

#### Temperature

Declining water levels between January and April led to increasing water temperatures that are also related to altitude. For example, the water



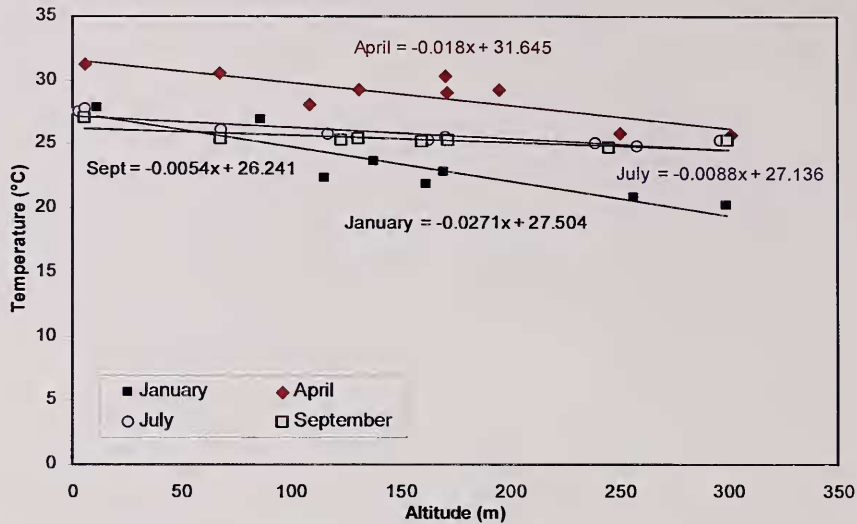


Fig. 2. Average water temperature measured at each sampling location during January, April, July and September 2006 with trend lines fitted.

temperature during January at Kafogo was 20.6°C, increasing downstream to 27.9°C at the Rokel Bridge. A line of best fit has been added to Fig. 2 to indicate the decrease with altitude, which was approximately 3°C/100m for January and 2°C/100m for April. Peak temperatures during the dry season in April ranged from 32°C near the estuary to 27°C at 300 m.amsl. During September, water temperatures had started to fall again, on average by 1°C to about 26°C, which was uniform across all sites. Most significantly, the temperature never dropped below 19°C.

### Conductivity

Conductivity ranged between 14 and 55  $\mu\text{S}\cdot\text{cm}^{-1}$  over the year. It tended to be higher in the dry season when lower water flows and evaporation can concentrate dissolved solids, and in April ranged from 35 to 55  $\mu\text{S}\cdot\text{cm}^{-1}$ . The high water levels and river flow rates observed during the July and September rains are associated with lower conductivity levels (14–29  $\mu\text{S}\cdot\text{cm}^{-1}$ ).

Most African forest rivers have a conductivity of less than 100  $\mu\text{S}\cdot\text{cm}^{-1}$  (Talling & Talling 1965; Welcomme 1985). They are waters of low mineralisation and generally very soft with extremely low calcium concentrations. The Seli, with other forest rivers in Sierra Leone (Payne 1975), clearly falls in this category. Although the water has a slight humic tint, its transparency, very low conductivity and pH varying around neutral suggests that this is a 'clear water' river, typical of tropical rivers whose water is derived through highly leached, old forest soils, according to the categorization of Sioli (1964).

### Dissolved oxygen

The level of dissolved oxygen at each site showed little seasonal change in the upper reaches (7.5–9.5  $\text{mg}\cdot\text{l}^{-1}$ ) but a wider range and generally lower

concentrations (5.0–7.2  $\text{mg}\cdot\text{l}^{-1}$ ) in the lower regions. The highest degree of oxygenation (8.0–9.5  $\text{mg}\cdot\text{l}^{-1}$ ) is consistently below the turbulent Bumbuna Falls. All sites were above 90% saturation levels over most of the year. The uppermost site registered the lowest value, with a low of 61% at the height of the dry season in April. The oxygen level varied between 5 and 10  $\text{mg}\cdot\text{l}^{-1}$  at all times, well above any level that would cause distress to the fishes, particularly amongst groups such as catfishes which have evolved a range of ancillary respiratory organs which enable them to use oxygen from surface air when the water becomes deoxygenated, as it often does in swamps.

### Fish Species Distribution

The results of the present survey, augmented by data from previous surveys, are shown in Table 2. The life colours of many of these species are poorly known or unknown and a photographic record is presented by Wakeford & Payne (2007). A series of photographs of species whose colours are not well known are included as Plate 1 and 2.

The most prominent species here was the golden-coloured barbel, *Barbus sacratus*, and the rock-haunting *Labeo parvus*. Both are typical of fast-flowing rocky rivers. *B. sacratus* is confined to the upper reaches above the falls, with only the very occasional small specimen being taken below the falls, probably having been washed down.

A further consistent feature of the assemblage above the dam was the presence of *Raiamas nigeriensis* and *R. steindachneri*. In July this site yielded a third species, *R. scarciensis*, which looks remarkably like a young tiger fish, *Hydrocynus forskalii*, with its slim silver body and the scarlet tail with a black edge (Plate 1). A second specimen was found below the Falls in October.

In the deeper pools with overhanging forest trees,



**Table 2.** List of species found at each site location during the 2006 baseline fish survey (●) and earlier collection of Payne (unpublished data) (○). Species status: ▲ regional endemic; C confined to some other small western coastal basins adjacent to region.

Family	Species	Jui - Estuary	Rokel Bridge	Magburaka	Below Falls	Below Dam	Above Dam	Kayakala	Kafogo	Fadugu	Total Length Max (cm)	Total Number	Status
Clupeidae	<i>Sierrathrissa leonensis</i>			○							6.7	1	C
Notopteridae	<i>Notopterus afer</i>	●	●	●							41.3	14	
Mormyridae	<i>Brienomyrus brachyistius</i>							●			9.9	1	C
	<i>Hippopotamyrus paugyi</i>		●	●		●	●				28.5	86	▲
	<i>Marcusenius meronai</i>		●				●	●			25.6	9	▲
	<i>Marcusenius mento</i>			○							18.2		
	<i>Marcusenius thomasi</i>	●	●	●			●				23.4	63	▲
	<i>Mormyrops breviceps</i>		●	●							47.1	4	C
	<i>Mormyrops anguilloides</i>		●	●							28.8	3	
	<i>Mormyrus tapirus</i>	●	●	●							50.0	20	▲
	<i>Mormyrus cf rume</i>		●								30.0	1	?
	<i>Petrocephalus pelligrini</i>		●	●		●	●	●	●		15.0	49	▲
	<i>Petrocephalus levequi</i>		●	●							13.8	2	▲
Characidae	<i>Brycinus longipinnis</i>		●	●		●	●		●		13.5	89	C
	<i>Brycinus macrolepidotus</i>	●	●	●							50.0	20	
	<i>Hydrocynus forskalii</i>	●	●	●							36.0	12	
Distichodontidae	<i>Ichthyborus quadrilineatus</i>		●								15.5	5	▲
	<i>Neolebias unifasciatus</i>			●		●					2.3	2	
Cyprinidae	<i>Barbus ablabe</i>					●	●		●	●	12.0	125	
	<i>Barbus</i> sp.					●	●		●	●	19.4	44	?
	<i>Barbus sacratus</i>			●		●	●	●	●	●	37.4	104	▲
	<i>Barbus leonensis</i>						●				-	2	
	<i>Barbus liberiensis</i>							●	●		11.0	12	▲
	<i>Labeo coubei</i>		●	●							50.5	2	
	<i>Labeo parvus</i>		○	●	●	●	●	●	●		41.7	203	
	<i>Leptocypris guineensis</i>			●							13.5	1	▲
	<i>Raiamas nigeriensis</i>			●	●	●	●		●	●	18.4	71	▲
	<i>Raiamas scarciensis</i>				●						23.1	1	
	<i>Raiamas steindachneri</i>				●	●	●				18.8	34	▲
	<i>Varicorhinus wurtzi</i>	●	●	●							45.3	29	C
Bagridae	<i>Auchenoglanis occidentalis</i>	●	●	●							46.4	5	
	<i>Chrysichthys johnelsi</i>		●	●							25.6	6	C
	<i>Chrysichthys nigrodigitatus</i>	●	●	●							34.6	43	
	<i>Chrysichthys maurus</i>	●									-	2	C
Schilbeidae	<i>Schilbe mandibularis</i>		●								20.2	10	▲
	<i>Schilbe micropogon</i>		●	●							24.2	17	C
Amphiliidae	<i>Amphilius rheophilus</i>					●					5.2	3	
Claridae	<i>Clarias anguillaris</i>		●					●			31.0	53	
	<i>Clarias buttikoferi</i>								●		42.4	1	C
	<i>Clarias laeiceps djalonensis</i>	●		●							49.2	4	▲
	<i>Heterobranchus isopterus</i>			○		●		●			43.3	8	C
Malapteruridae	<i>Malapterurus electricus</i>	●	●	●							26.6	8	

Table 2 cont...

Mochokidae	<i>Synodontis annectens</i>	● ●				-	1	C	
	<i>Synodontis cf filamentosus</i>	●				17.5	3		
	<i>Synodontis ansorgii</i>	○				17.2	5	▲	
	<i>Synodontis thysi</i>	●				18.8	2	▲	
	<i>Synodontis tourei</i>	● ● ●				24.5	24		
	<i>Synodontis waterloti</i>	● ●				13.1	4	C	
Centropomidae	<i>Lates niloticus</i>	● ● ●				37.0	17		
Cichlidae	<i>Hemichromis bimaculatus</i>			●		6.5	1		
	<i>Hemichromis fasciatus</i>	○ ● ● ● ● ●				25.0	115		
	<i>Anomalochromis thomasi</i>	●				5.2	1	▲	
	<i>Pelvicachromis humilis</i>		●			6.0	1	▲	
	<i>Sarotherodon caudomarginatus</i>	● ● ●				16.3	4	▲	
	<i>Sarotherodon occidentalis</i>	● ○			●	25.0	3	C	
	<i>Sarotherodon melanotheron</i>	○				25.9	-	C	
	<i>Tilapia brevimanus</i>	● ● ●				26.8	75	▲	
	<i>Tilapia buttkoferi</i>	○				26.5			
	<i>Tilapia louka</i>	○ ● ● ● ● ●				30.0	178	▲	
	<i>Tilapia joka</i>	○		●		12.6	1	▲	
	<i>Tilapia guineensis</i>	○				30.1	-	C	
	<i>Tylochromis leonensis</i>	● ● ●				21.9	36	▲	
	<i>Tylochromis jentinki</i>	○							
	Eleotridae	<i>Kribia kribensis</i>	○						▲
	Gobidae	<i>Awaous lateristriga</i>	● ● ● ●			15.3	7	C	
Anabantidae	<i>Ctenopoma kingsleyae</i>	● ● ● ● ● ● ● ●			19.7	49			
Mastacembelidae	<i>Mastecembelus libeniensis</i>	●			28.5	5	C		
Aplocheilidae	<i>Epiplatys fasciolatus</i>	●			-	7			
Mugilidae	<i>Liza grandisquamis</i>	● ●			48.4	2			
	Other estuarine species	●			-	-			
<b>TOTAL (ALL SPP)</b>		<b>20 25 50 38</b>	<b>16 19 6 17 8</b>			<b>-</b>	<b>1,734</b>		
<b>TOTAL ABOVE/Below FALLS (FW only)</b>		<b>62</b>	<b>29</b>						
<b>TOTAL FW SPECIES</b>		<b>68</b>							

typical calmer water species such as the anabantid *Ctenopoma kingsleyae*, the mormyrid, *Marcusenius thomasi* and the predatory cichlid *Hemichromis fasciatus* were commonly found. However, this last species occurs almost ubiquitously along the river (Table 2).

The rivers of Sierra Leone are characterised by their cichlids, particularly their distinctive *Tilapia* species. However, immediately above the dam, as above the falls, only *Tilapia louka* was common. Some of the larger individuals, even in January, were developing their breeding colouration of bright red on the edge of the dorsal fin and the corners of the caudal fin together with a bright gold body colour with red in the pectoral region. This was noted through to July.

The number of catfish species in the samples increased towards the rains as more moved upstream to spawn. The most distinctive catfish groups before the falls were the schilbeids and of the genus *Synodontis*. These were entirely absent above the falls. The *Synodontis* species were particularly diverse, and seven species were found in the river as far as Magburaka. By Bumbuna (138 m.asl) below the falls, however, there were only two species,

*S. tourei* and *S. waterloti*, presumably as the river course becomes steeper and habitats become less favourable to *Synodontis* spp. generally. Upstream of the falls they disappear completely (Table 2). These last named species we examined for taxonomic distinctness since *S. tourei* had previously only been found in the upland streams of the Fouta Djallon of the Guinea Highlands, within the catchment area of the Upper Bafing basin which flows into Senegal. Similarly, *S. filamentosus* had also not previously been found in Sierra Leone but has been found in the Upper Niger. The Rokel population has the very characteristic filamentous extension to the dorsal fin which almost reaches the base of the caudal fin (Paugy *et al.* 2004). It may, therefore, be a variant of *S. filamentosus* or a closely related but previously unrecognised species. Bearing in mind the proximity of the Upper Niger basin to that of the Seli, the headwater streams maybe with 20–30 km from each other, it would not be surprising if species from the Upper Niger had reached the Seli during their evolutionary history.

Schilbeids are fast-swimming, silvery open water species. Two species were recorded in the survey. Previously these were ascribed to the genus

*Eutropius*, but a recent revision has subsumed them into the widely distributed genus *Schilbe* (De Voss 1995). Thus they are now referred to as *Schilbe micropogon* and *S. mandibularis*. Neither were found above the falls and both are characteristic Upper Guinean species.

Another group which proved to be diverse within the fish assemblage of the Seli River were the Mormyridae. Of the 11 species taken, most occurred as far as the falls and five were also found above the falls. One species, *Brienomyrus brachyistius*, was only taken in the streams of the upper reaches.

Extended fixed gill nets, some over 100 m long, were set by fishermen across the large, deep pool immediately below the falls. The species caught had already been recorded but they did produce very large specimens of *Brycinus macrolepidotus* of up to 50 cm long (Table 2). These specimens had bright red fins and areas on the flanks of adults more than 35 cm. In the Chad basin this species is known to grow to 53 cm and 2.9 kg. The Guinean and Sudanian forms vary in that the fins are generally orange, but only in the River Cavally is the colour red/vermillion, as for the Rokel/Seli specimens (Leveque & Paugy 1984). There is no mention of the four black longitudinal lines that also appear in the adults from the Seli population, which may be a characteristic of the Guinean form. Similarly, large specimens of the cyprinids *Labeo parvus* and *Varicorhinus wurtzi* were also caught (Table 2).

Fishermen below the falls stated that in January the water is still quite cold (see Fig. 2) and that better catches were taken in the warmer months of February and March, i.e. during the dry season. Peak catches, however, were taken during the beginning of the rains when the fish were moving. Asked if fish could move up the falls, they were unanimous in asserting that they could not, but that fish were washed down. This is probably the case for *B. sacratus* since a few smaller individuals were found below the falls, but the fishermen also stated that this species is found all the way up to Kafogo, which proved to be correct (Table 2). It is worth noting that *V. wurtzi* was found at a number of points downstream and may well be an ecological replacement species for *B. sacratus*, i.e. occupying a similar niche downstream. Quite large specimens of both were taken in the present survey. Fishermen at Kafogo stated that 10 years ago the golden fish (*B. sacratus*) were "bigger than a sugar bag" (75 cm) although the use of dynamite in the 1990s destroyed the population and such big individuals had not been seen recently. The maximum recorded size in the survey was 37.4 cm (Table 2); such large fish do still exist but presumably much less frequently in the opinion of the fishermen. Dynamite fishing has been a problem in Sierra Leone. It is illegal under Sierra Leone law but still occurs. The damage referred to above by the fishers was related to a period of mineral exploration by expatriate companies.

The fishermen said that species, such as the Nile perch, *Lates niloticus*, the tiger fish, *Hydrocynus forskalii*, and the large characin, *Brycinus macrolepidotus*, do

not occur above the falls. This ultimately proved to be correct (Table 2). The largest Nile perch was taken near Bumbuna Bridge measuring around 90 cm (Table 2), but none were ever seen above the falls.

Sampling in the upper reaches of the river included samples at sites at a headwater stream near Fadugu, the highest point sampled (299 m.amsl), and a little beyond at Kafogo which is on the banks of a larger tributary (Table 2). The branch at Kafogo (Table 2) showed an assemblage similar to that in the vicinity of the dam with *B. sacratus*, *L. parvus*, *H. fasciatus* and *Ctenopoma kingsleyae*. Other species included the large tilapia, *Sarotherodon occidentalis*, from one of the larger pools, and the catfish *Heterobranchus isopterus*. *Sarotherodon occidentalis*, as a microphageous detritus/algal feeder (Payne & McCarton 1983) should also be more typical of lower reaches of the river. However, this may be of feature of the low gradient of the river at this point, with a series of riffles and quite calm pools (Table 2).

The second much smaller stream near Fadugu, contained mainly small *Barbus* species including *B. liberiensis* along with the characin *Brycinus longipinnus*, both of which are typical of small, cooler headwater streams in the region. Unusually, the water in both branches was quite turbid rather than clear. Again, this could be due to the low gradient here although deforestation of the surrounding hills of the catchment area may also be significant.

Catfishes became much more common downstream, particularly at the Rokel Bridge where the two species of *Chrysichthys* seem to predominate, along with an *Auchenoglanis* species and a number of *Synodontis* species (Table 2).

At Magburaka a fisher's catch from a swamp during January included a large number of young-of-the-year of the catfish, *Clarias*, demonstrating the lateral migration of such species up small streams and marginal swamps to breed. The catch also contained the colourful small cichlid *Anomalochromis thomasi*, which is to be found in smaller streams. A small clear water, inflowing stream also yielded *Brycinus longipinnis*, typical of such habitats, as described for the inflowing stream at Bumbuna.

A final component of the species assemblage in the Rokel/Seli is the estuarine element. The conditions at the Rokel Bridge are under tidal influence but were freshwater when sampled although a number of estuarine species are found here. These include a sole, *Cynoglossus* sp., a pompano, *Caranx* sp., and a common croaker *Pomadasys jubilini*. Not found in the present survey but recorded earlier have been the two tilapias, *Tilapia guineensis* and *Sarotherodon melanotheron* (Payne unpublished data). These are exclusively confined to estuaries and are widely distributed in those of Sierra Leone (Payne 1983). They add another element to the remarkable diversity of tilapia-like cichlids in the rivers system.

One estuarine species, the grey mullet, *Liza grandisquamis*, was recorded as far up as Magburaka, some 140 km from the estuary, and this during the height of the rains when the influence of freshwater was at a maximum. A species of goby, *Awaous*



*lateristriga*, was found above the falls at Bumbuna, at least 190 km upstream from the estuary. However, gobies of the genus *Awaous* are diadromous and live their entire adult lives in fresh water. The Malagasy, Caribbean and Central American congeners of *Awaous lateristriga* are routinely found above major waterfalls at altitudes in excess of 500 m.amsl.

#### Changes in Abundance

The variety of methods used suggests that total numbers caught by species only give an approximate indication of abundance (Table 2). Species such as *Labeo parvus*, *Hippopotamyrus paugyi* and *Tilapia louka*, however, emerge as generally quite common whilst some, such as *Raïamas scarciensis* and *Clarias beutikoferi*, are only known from one or two specimens.

The major seasonal shift show by large numbers of *Barbus* species, particularly *B. sacratus*, along with *L. parvus* and the small *Brycinus longipinnis* appearing in the upper reaches during April and July. This is consistent with the upstream spawning migrations known for these types of fishes with the advent of the rains (Welcomme 1985; Payne & McCarton 1983). In April also, large numbers of *Synodontis* spp. appear at Magburaka as if moving upstream in a spawning migration. They do not, however, move above the falls which appears to be a barrier to fish movement.

#### Yield Estimate from the Rokel/Seli River

Higher potential yields are taken by the fishers during the dry season than in the rainy season. This may increase by a factor of 20. Thus at Bumbuna, for example, total estimated catches increased from 144 kg.km<sup>-1</sup> during the rainy season to 2.7 t.km<sup>-1</sup> during the dry season.

An average of both seasonal results was used to illustrate the expected annual yield available from the Rokel/Seli River. Average estimated yields increase downstream. The relationship between the distances from the source of the river and yield is not linear, but is described as a power function similar to Welcomme (1976) where  $\text{yield} = 0.053 * d^{0.8082}$ , where *d* is the distance (km) from the source of the river. The average annual potential yield increases from 0.87 t.km<sup>-1</sup> in Kafogo, to 1.42 t.km<sup>-1</sup> in Bumbuna, and 2.58 t.km<sup>-1</sup> in Magburaka. The surveyed yields here are rather lower than those predicted by the relationship of Welcomme (1976) but they are most likely minimum values, since catches from a number of other part-time and subsistence fishers are unlikely to have been accounted for, including women and children using hand nets, hook and cast nets. The arrival of seasonal fishers with powerful gear has been noted for the River Taia (Payne *et al.* 1989) and was reported in the Rokel and seems to be a feature of Sierra Leone river fisheries which has been similarly unaccounted for in this study.

## DISCUSSION

#### Species assemblages and zonation

There clearly is a progressive reduction in the number of species upstream (Table 2). Exceptions to the trend are the lowest altitude sites at the Rokel Bridge and the estuary at Jui, but these were only sampled on one occasion each as opposed to four (January, April, July and September) at the other sites. The relationship between species number and elevation is shown in the river profile (Fig. 3). A regression of species number on altitude, excluding the under-represented site at the Rokel Bridge, showed a highly significant inverse relationship ( $r = 0.86$ ,  $p = 0.01$ )

The species number falls from 41 at Magburaka, where the river is wide with the deep-flowing, depositional nature of the lowland portion of the river, to eight at Fadugu, at which point the river is little more than a turbulent stream. The river from Fadugu to the falls follows a very steep course (Fig. 3) typical of the erosional, fast-flowing rhithron zone typified by more species (16–19) than at the upper stream at Fadugu, but far fewer than the downstream lowland portion. The rocks of this region are also typically covered at the waterline by encrusting plants of the Podostemaceae (Payne 1986). The construction of the dam has had little effect on diversity at this point judging from species numbers above and below, probably because it is not yet functional (Fig. 3; Table 2).

Species number differs little between Magburaka to the point below the falls, while the Falls represent the greatest species discontinuity along the river system, as well as the point of maximum change in slope, marking the transition from lowland (potamon) to upland zones (rhithron) of the river. Thus, compiling the total numbers of freshwater species gives 55 for below the falls and 29 for above. In a comparable review of the Ganges basin where the change from upland to lowland sectors is almost as distinctively marked in its descent from the Himalayas, some 54 species were found in the upland sector and 107 from the lowland (Payne *et al.* 2004), a very similar ratio to that for the Rokel/Seli.

In comparable fashion, a number of species which occur in the Benue River have been unable to colonise the Chad basin because of the Gauthiot Falls (Leveque & Paugy 1999). There are similar cases in rivers descending the Upper Niger basin from the Fouta Djallon where, for example, the number of species found below the falls at Tinkisso was 19 compared to eight above (Daget 1962). The relative reduction is also similar, although it is not clear whether this is due to progressive increase in slope or altitude or whether it is due to solely to the falls. On the River Mono, Paugy & Benech (1989) noted that species tended to increase downstream towards an asymptote, which seems to be the case here. The same pattern is seen on a small montane river on the Freetown Peninsula, Sierra Leone where the number of species on the coastal strip at 25 m.amsl was 16,

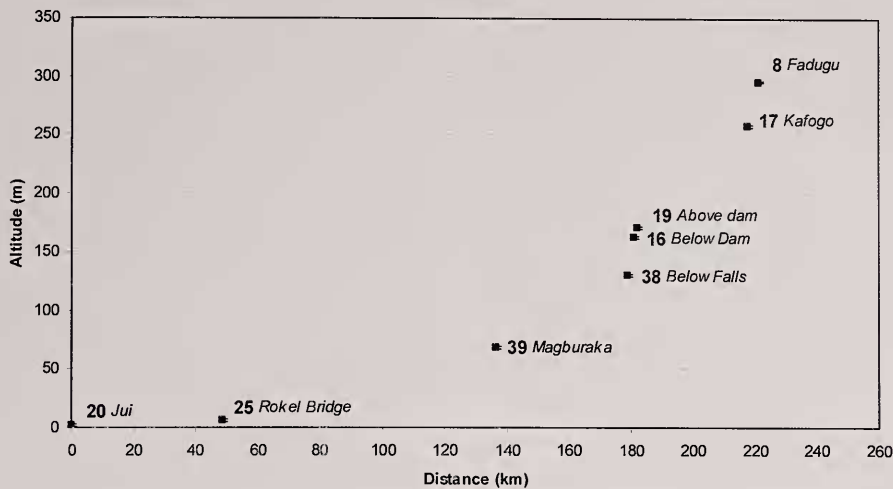


Fig. 3. The number of species taken at each location in relation to altitude (meters above mean sea level) and distance from estuary (km).

declining to four at 100 m.amsl and further to two species at 400 m.amsl (Payne 1986).

Of the species above the falls, nine are not found lower down. Of these, four are small *Barbus* species. Of the small barbids, *B. liberiensis* is only found at the two highest sites (260 m.amsl and 295 m.amsl) where the streams are fast flowing. In the mountainous terrain of the Freetown Peninsula *B. liberiensis* was frequently found to occur alone at the highest points of streams at altitudes of 250–400 m.amsl in a similar fashion to the higher sites on the Seli (Payne 1975, 1986). On the Peninsula in the high streams where *B. liberiensis* is not found, the last species remaining is the small cichlid *Hemichromis bimaculatus* (Payne 1986). This species has been found in one location above the dam on the Seli but is uncommon (Table 2). Daget (1962) commented that above waterfalls the high streams of the Fouta Djallon massif in the Guinea highlands were dominated either by small barbids or by *Hemichromis*, but never by both, a feature he ascribed to the predator pressure on the barbids by *Hemichromis* when they are prevalent. The same feature is demonstrated in the upper regions of both the Seli River and the Peninsula streams.

Another characteristic species of small fast-flowing streams in the region is the small catfish, *Amphilius rheophilus*, with suckorial mouthparts which enable it to cling onto the underside of rock surfaces when streams are in spate. It was only found in a small inflowing stream in the upper reaches in the aftermath of the rains.

The fish assemblage above the falls is characterised by cyprinids generally such as *Barbus* species including *B. sacratus* and also *Labeo parvus* among the larger species – although the latter is widely distributed throughout the whole system wherever there are rocks – and two of the micropredator *Raiamas* species. In Europe, the turbulent, well-

oxygenated upper reaches of rivers are characterised by strong swimming, often migratory, salmonids, and the lower reaches are characterised by deep bodied cyprinids (Huet 1949). The salmonid role appears to have been taken over by the cyprinids in west African rivers, particularly the larger species, which are also usually migratory. So *Barbus sacratus* could be regarded as the trout of the Seli which, given the significance of trout in European water management, could make it a key indicator species of anthropogenic impacts.

Below the falls a high proportion of species are not found above. A large number of these are catfishes, particularly *Synodontis* spp. Of the 15 catfish species only found in the lowland reaches, eight are *Synodontis* spp. Catfishes are well adapted to the often turbid, slower-flowing waters in this region, with highly tactile barbels which facilitate the use of touch and chemical stimuli when light is low (Lowe-McConnell 1975). Most catfish species are bottom dwellers, but the two *Schilbe* species are midwater predators and very mobile. The falls may present a physical barrier to such mobile species or to any migratory type, which includes most cyprinids and catfishes.

There are also cyprinids below the falls including the ubiquitous *Labeo parvus* and another *Labeo*, *L. coubie*. Another larger cyprinid *Varicorhinus wurtzi* which does not appear in the upper reaches, seems to replace *B. sacratus* as the large upstream species. *V. wurtzi* is rather darker and deeper bodied than the more fusiform *B. sacratus*; *L. coubie* is also a deeper bodied species which often typifies fish of the slower moving, turbid lower reaches. Proportionally, however, the cyprinids are much less significant in the lower reaches compared to the upper, with nine species appearing in the upper river above the falls and four in the lower reaches (Table 2).



Most larger cyprinid and catfish species migrate upstream during the early rains. Consequently such species tend often to decline when dams are closed and lacustrine conditions replace riverine (eg. Lowe-McConnell 1987). This could be expected when the Bumbuna Dam is finally closed and a reservoir forms.

Neither of the two specialist top predators, *Lates niloticus* and *Hydrocynus forskalii*, is to be found above the falls. In this respect, it is notable that *L. niloticus* is thought never to have naturally colonised Lake Victoria or Lake Edward from the rest of the Nile system due to the intervening presence of falls or rapids below the lake outflows. It has, however, been suggested that strict top predators are often large in size and are consequently generally restricted to lower basin zones (Welcomme et al. 2006). Another species that has not made the transition is the characin, *Brycinus macrolepidotus*, which can also grow to a large size (Table 2).

A group particularly characteristic of the lower river below the falls are the cichlids, especially the tilapiine cichlids, the nest-guarding leaf chowers, *Tilapia*, and the paternal/biparental, mouth-brooding, microphageous *Sarotherodon* species (Trewavas 1983). In addition, there are two *Tylochromis* species (Table 2) which are of similar size and shape, and which are also mouth-brooders. Stiassny (1989) identified three species in the region of which *T. leonensis* and *T. jentinki* have been found in the Rokel/Seli River. More specific information on their feeding and reproductive ecology will be the subject of a separate paper.

In this relatively small river basin eight species of true tilapia have been found plus the *Tylochromis* species (Table 2). In the entire Nile basin there are only four *Tilapia* species (Payne & Collinson 1983), whilst the neighbouring Niger basin has just six. Even in Lake Malawi, renowned for its cichlid diversity, there are but six *Tilapia* species (Philippart & Ruwet 1982). The third tilapine genus, *Oreochromis*, is completely absent from the Rokel/Seli system, even though it is common in many African lakes and rivers further east, including the Niger. The diversity of the tilapia-like cichlids is greatest in the lowland potamon zone where all species are found. Two species, *T. guineensis* and *S. melanotheron* are confined to the estuary where they live and spawn in waters of up to 36 ppt salinity (Payne 1983). Of the others, *T. louka* has spread throughout the whole system and *T. joka*, a small, rock-dwelling species occurs wherever there are rocky areas in quieter waters either above or below the falls. *Tilapia joka* is unusual for a tilapia, in that field observations show it feeds and breeds around holes and crevices in rocky areas.

*Sarotherodon* and *Tylochromis* species tend to be confined to the lowland sector below the Falls. One exceptional specimen of *S. occidentalis* was taken well upstream at Kafogo (Table 2) although this was in a relatively calm, deep pool, untypical of the sector. What this does show, however, is that when the habitat is suitable, a species can colonise it. These tilapia-like species are relatively sedentary and their

parental behaviour seems to be better adapted to calmer waters since all species need to make nests which requires an abundance of sedimentary areas, a characteristic of the depositional lowland sectors. These features, together with the microphageous feeding habit of *Sarotherodon*, which feed on plankton and detritus (Trewavas 1983), tend to favour tilapia when dams create lacustrine conditions. After the Akosombo Dam created the Volta Lake on the River Volta in Ghana, *S. gallileus* became a major species in the commercial fishery (Lowe-McConnell 1987), while noting that *O. niloticus* was the most commercially important species in Volta Lake. Significantly, in a small lake formed from a flooded quarry within the catchment area of the lower Rokel, *S. occidentalis* was found to be very abundant. It is probable, therefore, that *S. occidentalis* will become a feature of any fishery that develops behind the Bumbuna Dam when it is finally closed.

The high diversity of the tilapia-like cichlids has two further applied consequences. First, all but the two estuarine species were found to be confined to the Guinean region and the majority are regional endemics, which, given the significance of tilapia in aquaculture, should be conserved as a great pool of genetic diversity for aquaculture in the future. Second, given the need for this conservation and noting that there are no endemic *Oreochromis* species, the introduction of exotic species such as *O. niloticus*, which has already happened on a limited scale for aquaculture in Sierra Leone, should be discouraged, given the great damage already done to tilapia genetic diversity by escapees elsewhere in Africa. Faced with this same problem, the Government of Malawi for example, has decreed that only their endemic tilapia species should be used for aquaculture. Given their very different reproductive systems, the likelihood of introgressive hybridization between *Oreochromis* and *Sarotherodon* is slight. However, *Oreochromis* is characterized by both greater fecundity and extreme sexual precocity, characteristics which would allow them to out-compete and ultimately displace *Sarotherodon* species if they escape, which they inevitably will.

It is possible to identify zones, after the manner of Huet (1949), for African rivers (Illies & Botosaneanu 1963). Four zones, including the estuary, have been characterized in the rivers of the Atlantic Forest region of Brazil (Ferreira & Petrere 2009). The uppermost, from low order streams, for the Rokel/Seli at about 260 m.amsl to 300 m.amsl, is characterised by small *Barbus* species, specifically *B. liberiensis*. On the Peninsula and in the Fouta Djallon some of the streams in the upper zone instead have only *Hemichromis bimaculatus*. Below this small *Barbus* zone, down to the junction with the potamon boundary, is a zone characterised by large cyprinid species, in this case *Barbus sacratus* and *Labeo parvus*, with the former being the most characteristic. During the upstream spawning migrations in the early rains, these species may move up into the headwater, 'small *Barbus* zone' to spawn. In the Ganges river there is a distinct parallel, with a large cyprinid zone



starting at the rhithron/potamon boundary but in this case characterised by the cyprinids *Schizothorax*, the snow 'trout', and *Tor*, the mahseers (Payne et al. 2004).

Below the large cyprinid zone, throughout the lowland rhithron sector is a zone characterised by cichlids and catfishes. In the Rokel/Seli they account for 13 and 16 species respectively. In other African river systems, the larger cichlids may be less diverse and better represented by their relative abundance. Below this lower rhithron catfish/cichlid zone lies the fourth zone, the estuary.

There is one further zone or distinctive habitat. This is lower order inflowing lowland streams. These characteristically hold the young of the year of main channel species, such as *Clarias*, *Mastacembelus* and mormyrids together with some distinctive smaller species, especially cichlids such as *Pelvicachromis humilis* and *Anomalochromis thomasi* together with cyprinodonts such as *Epiplatys* spp., and some more widely distributed small stream species like *Brycinus longipinnis*. These small species essentially on the more isolated margins of the river network often have a high degree of endemism. These are also the populations which were seen to be most exploited by the women and children with hand nets. It could be that this relatively low technology fishing could actually be having a disproportionate impact on biodiversity.

#### Relative Diversity

The total number of freshwater species found during this survey on the Rokel/Seli Basin was 68 (Table 2). A general relationship between the total number of species occurring in a basin and its area has been described for Africa by Welcomme (1985) as:  $N = 0.449 A^{0.434}$ , where  $N$  is species number and  $A$  is basin area ( $\text{km}^2$ ). Since the basin area of the Rokel/Seli is  $10,620 \text{ km}^2$  this means that the most probable expected number would be 39. The Rokel/Seli has rather more than this and perhaps could be a biodiversity hotspot for fish. The appraisal of Abell et al. (2008) suggests a high number of species in the region compared to other areas further indicates a hotspot.

A checklist of fish species in Sierra Leone from all sources, including specimens in major museums, suggests a number of 95 species (Paugy et al. 1989). One of the contributing factors to the Rokel/Seli not attaining this is the lack of lowland freshwater swamps in the coastal region, which often contributes significantly to fish diversity (Abell et al. 2008). There were also some species missing which are common elsewhere, such as *Hepsetus odoe*, although this is regarded as a predator of smaller tributaries.

Of the species recorded (Table 2) 35% (24) of those identifiable are found only in the Guinean region of which six, *Marcusenius meronai*, *Petrocephalus loequei*, *Leptocypris guineensis*, *Raiamas scarciensis*, *Clarias laeviceps* (as its subspecies, *dialonensis*) and *Synodontis thysi*, are endemic to Sierra Leone and south west Guinea (derived from Trewavas 1983, and Paugy et al. 2004). A further 24% are also only to be found

in some of the other small coastal basins outside the region leaving fewer than 40% in common with other basins across wider Africa, including the neighbouring Niger. A comparative assessment of species assemblages between regional rivers will be the subject of a separate publication, but suffice to draw attention to the distinctiveness of the fish assemblage of the Seli/Rokel. This distinctiveness may have come about by the periodic interpluvial spread of the surrounding Sahara, in step with the interglacials, over geological time thereby further isolating the region and producing an 'island effect' which promoted differentiation.

#### ACKNOWLEDGEMENTS

This study was funded by The Bumbuna Hydroelectric Project. We are grateful for the kind assistance of Miss Elizabeth George and Mr Charles Mustapha from the Institute of Marine Biology and Oceanography (IMBO) at the University of Sierra Leone, local fishers Mr Abdul and Mr Kall at Bumbuna, and Minkailu Bantama and Kaduru Bantama at Kafago for helping to provide fish samples throughout the survey period. We are further grateful for the support from Paul and Pirran Driver of Nippon Koi, UK.

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## PLATE 1



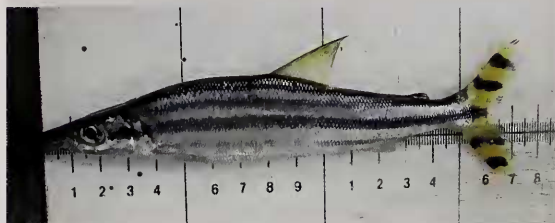
*Mormyrus tapirus*, 509 mm SL, Mgaburaka, Rokel/Seli River (Robert Wakeford)



*Mormyrops breviceps*, 473 mm SL, Mgaburaka, Rokel/Seli River (Robert Wakeford)



*Brycinus macrolepidotus*, 448 mm SL, below Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



*Ichthyborus quadrilineatus*, 191 mm SL, Mgaburaka, Rokel/Seli River (Robert Wakeford)



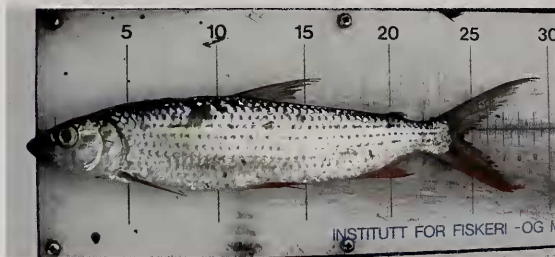
*Barbus sacratus*, 284 mm SL, above Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



*Varicorhinus wurtzi*, 406 mm SL, below Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



*Raiamas scarciensis*, 239 mm SL, below Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



*Hydrocynus forskalii*, 298 mm SL, below Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



PLATE 2



*Tilapia buttikoferi*, 279 mm SL, River Taia (Bernadette McCarton)



*Sarotherodon occidentalis*, 344 mm SL, breeding colouration, Rive Taia (Bernadette McCarton)



*Tilapia louka*, 137 mm SL, above Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



*Tilapia brevimanus*, 194 mm SL, Magburaka, Rokel / Seli River (Robert Wakeford)



*Synodontis waterloti*, 158 mm SL, Mabile River (Robert Arthur)



*Synodontis tourei*, 222 mm SL, below Bumbuna Falls, Rokel/Seli River (Robert Wakeford)



*Synodontis cf. filamentosus*, 169 mm SL, Mgaburaka, Rokel/Seli River (Robert Wakeford)